Special Topics on Basic EECS I
VLSI Devices
Lecture 14

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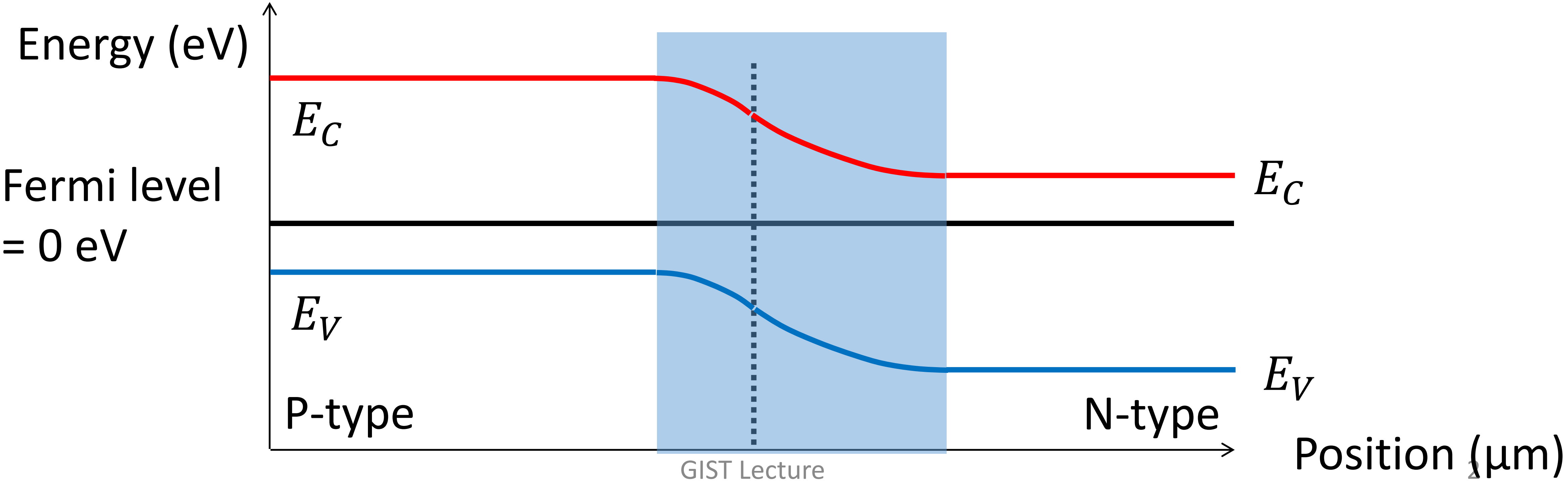
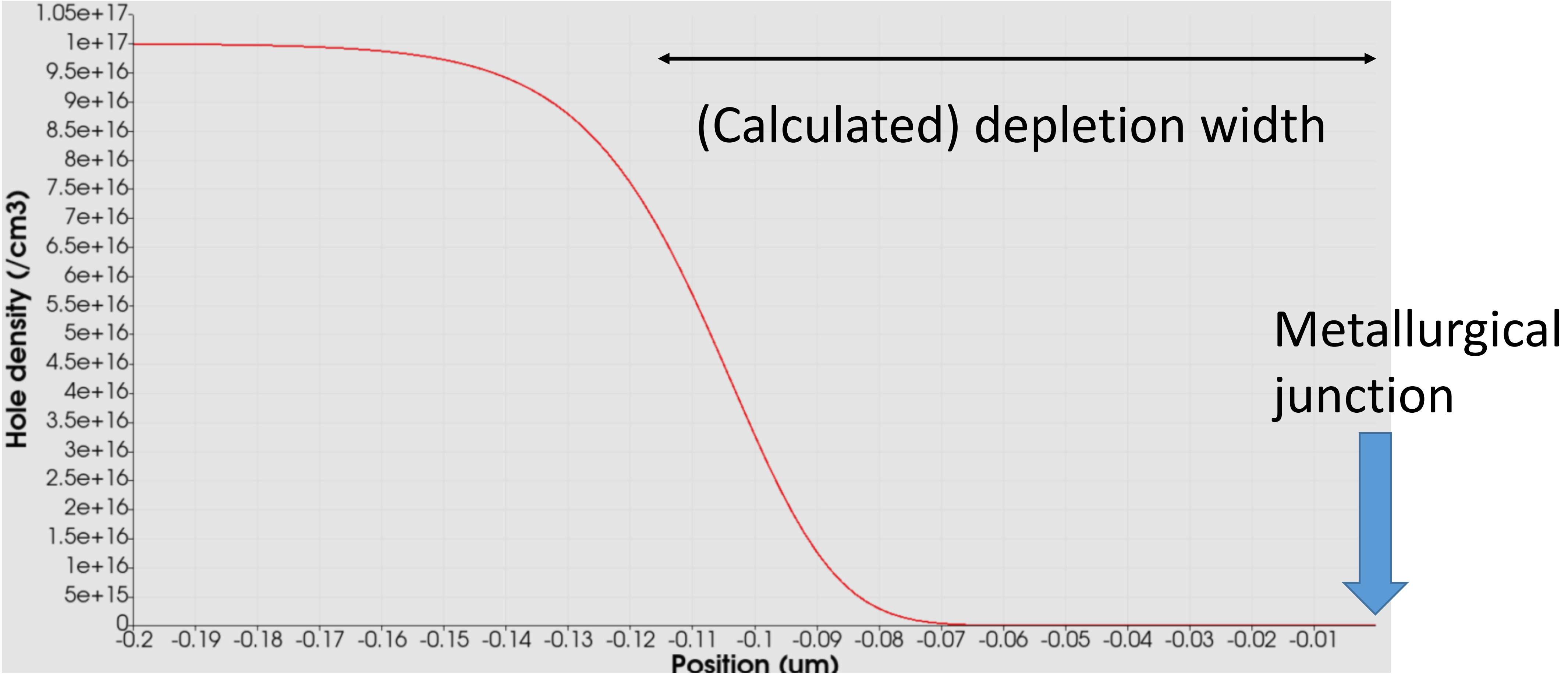
Energy band diagram, again

- Near the junction, smooth transitions of E_C and E_V
  - Parabolic curves
  - Energy barrier seen by each carrier



Revisiting the depletion approximation

- Numerical solution (N_d = 10^{20} cm^{-3} and N_a = 10^{17} cm^{-3})
  - The hole density does not drop abruptly. (Length scale: L_D)



Externally biased junctions

- Consider a positive bias applied to the p-type contact. (Forward-bias)
  - Boundary condition for the electrostatic potential

$$\phi\left(V = V_{app}\right) = \phi(V = 0) + V_{app}$$

  - Boundary condition for the quasi-Fermi potentials

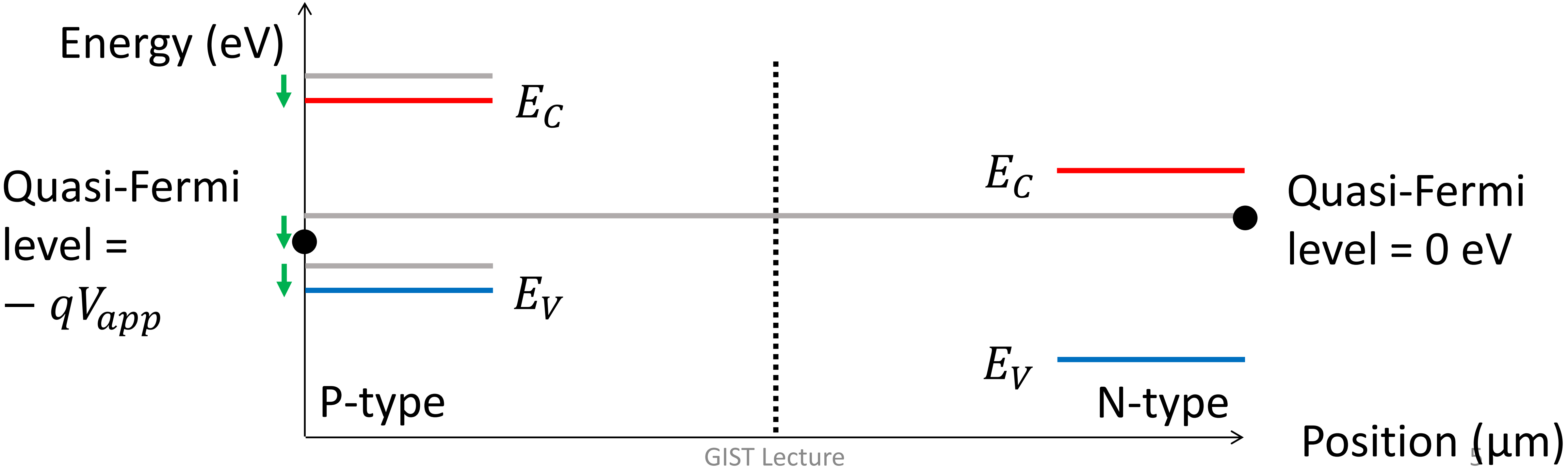
$$\phi_n\left(V = V_{app}\right) = V_{app}$$
$$\phi_p\left(V = V_{app}\right) = V_{app}$$

Energy band diagram

- We cannot define the Fermi level any more.
  - Still, quasi-Fermi potentials are available.
  - The total potential difference is

$$\phi_{bi} - V_{app}$$

Taur, Eq. (2.81)

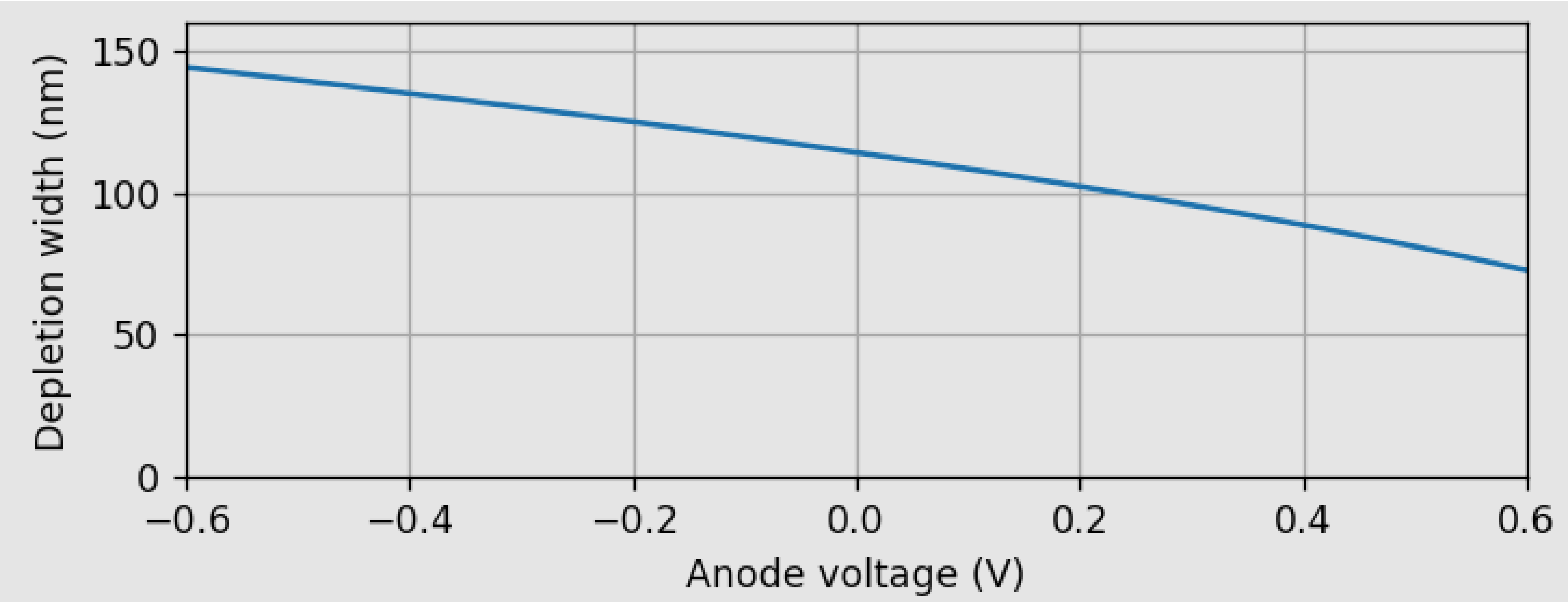


Depletion width at non-equilibrium

- Since the potential difference is $\phi_{bi} - V_{app}$,

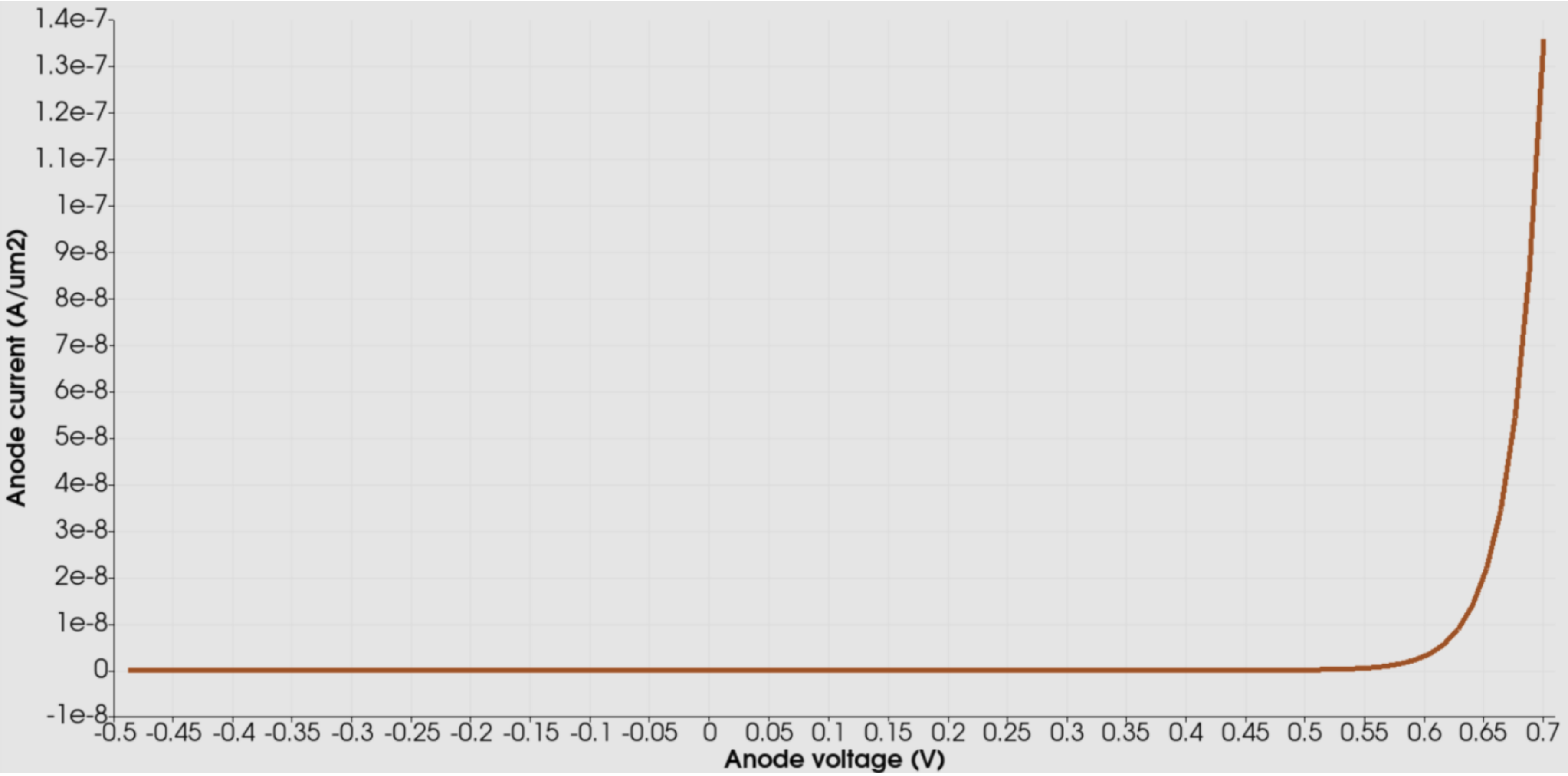
$$W_d = \sqrt{\frac{2\epsilon(N_a + N_d)\left(\phi_{bi} - V_{app}\right)}{qN_aN_d}}$$

  - Example) N_d = 10^{20} cm^{-3} and N_a = 10^{17} cm^{-3}



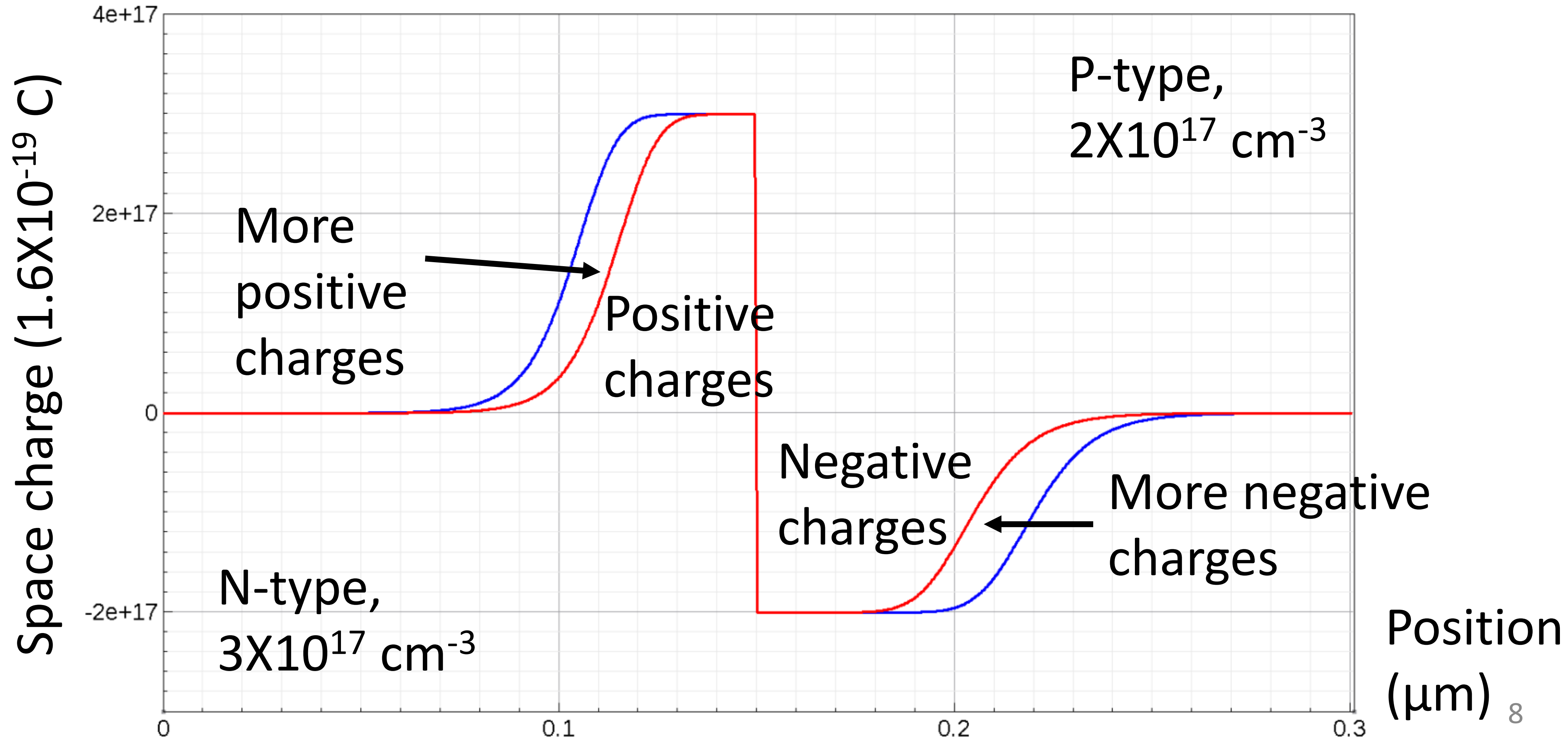
PN junction as a rectifier

- Forward biased: $\phi_{bi} - V_{app}$ is lower than the equilibrium value.
- Reverse biased: $\phi_{bi} - V_{app}$ is higher than the equilibrium value.



Space charge

- -0.5 V (Blue) and 0 V (Red)



Depletion-layer capacitance

- When 0.5 V is applied to the n-type region, we have additional positive charges in the n-type region.
  - The depletion-layer capacitance is

$$C_d \equiv \frac{d}{dV_{app}}\left[-qN_a W_d \frac{N_d}{N_a + N_d}\right] = -q\frac{N_a N_d}{N_a + N_d}\frac{dW_d}{dV_{app}}$$

  - It is readily shown that $\frac{dW_d}{dV_{app}} = -\frac{\epsilon(N_a+N_d)}{qN_aN_d}\frac{1}{W_d}$.
  - Therefore,

$$C_d = \frac{\epsilon}{W_d}$$

Taur, Eq. (2.83)

  - Its physical interpretation?

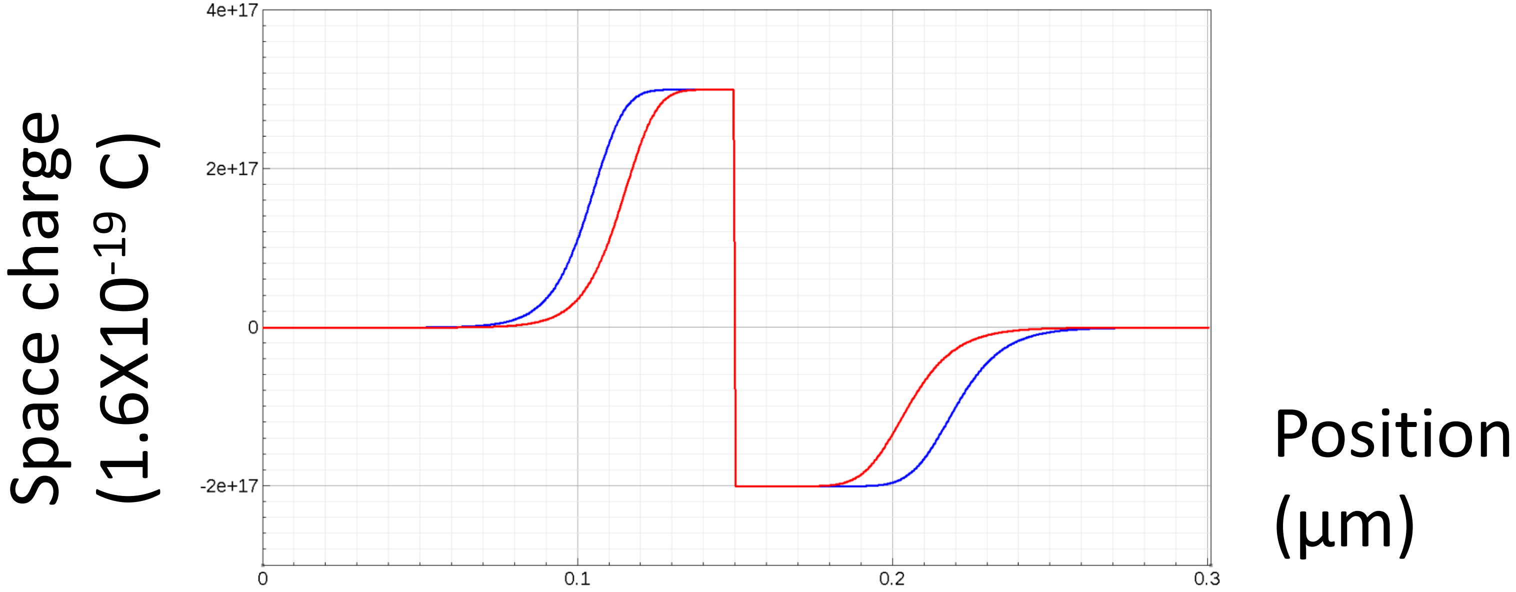
Estimation

- Distance between two curves: ~ 10 nm (n-type) & ~ 15 nm (p-type)
  - Then, for 0.5 V difference,

$$\Delta Q = q \times 4.8 \times 10^{-8}\ \mathrm{cm}^{-2}$$

  - The capacitance becomes

$$C_d = 9.6 \times 10^{-8}\ \mathrm{F\ cm}^{-2}$$



Thank you!